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Appendix A
INTERIM REPORT ON THE ANALYSIS OF BUILDING AND FIRE CODES AND PRACTICES

A.1 INTRODUCTION

As stated in Chapter 2, one of the objectives of the National Institute of Standards and Technology (NIST) Investigation of the World Trade Center (WTC) disaster is to determine the procedures and practices that were used in the design, construction, operation, and maintenance of the WTC buildings. (For other objectives refer to http://wtc.nist.gov.) Since WTC 1, 2, and 7 were designed according to the New York City Building Code, it is important to understand how this code compared with contemporaneous building codes. This appendix summarizes the structural and fire provisions of the 1968 New York City Building Code and compares them with a number of building codes that existed when WTC 1, 2, and 7 were designed, as well as the 2001 edition of the New York City Building Code.

As a result of devastating fires in major cities of the U.S. such as Boston, New York, Chicago, and Baltimore in the late 1800s, the first model building code was developed by the fire insurance industry to minimize future fire losses. The National Board of Fire Underwriters (predecessor of the American Insurance Association) published the *National Building Code* in 1905. Subsequently, the Pacific Coast Building Officials Conference (predecessor of the International Conference of Building Officials) issued the *Uniform Building Code* (UBC) in 1927, the Southern Building Code Congress International Inc. published its *Southern Standard Building Code* (SBCCI) in 1946, and the Building Officials and Code Administrators, Inc. (BOCA) published the *Basic Building Code* in 1950. In the mid-1980s, the Basic Building Code was changed to the *BOCA National Building Code* (NBC). These regionally used model building codes were revised annually to incorporate developments in new materials and construction methods, and new additions were published every three years.

It should be pointed out that provisions in these model building codes establish minimum requirements to safeguard life, health and property and public welfare by means of regulations pertaining to the design, construction, and quality of materials, use and occupancy, and maintenance of buildings. When buildings are designed, constructed, and maintained according to building code requirements, they are considered to have met minimum requirements. While building code regulations address a number of objectives demanded by society, the primary objectives of building codes are structural stability and fire safety.

Before the issuance of the *International Building Code* (IBC) in 2000, which was published by the International Code Council (an amalgamation of the three regional code organizations), most local and state building codes in the U.S. were patterned after one of the three model building codes, UBC, SBCCI, or NBC. These model codes evolved in the mid-20th century to incorporate regional differences in construction materials and practices. When adopted by local jurisdictions, the model building code becomes a legal document and code provisions become mandatory laws. A number of major cities in the U.S. have developed their own building codes to meet their specific needs, such as San Francisco for earthquake resistant design and New York City for high-rise buildings design.

The National Fire Protection Association (NFPA) in the early 1900s initiated the development of a "life safety code" for safety of building occupants. This code, while not a building code, is frequently used as a supplement to the building codes. In 2002, NFPA also published a model building code known as the *NFPA Building Construction and Safety Code* (NFPA 5000).

The Port of New York Authority (PONYA) (whose name was changed to the Port Authority of New York and New Jersey [PANYNJ] in 1972) is an interstate agency that was established in 1921under a clause in the U.S. constitution that permits compacts between states. As an interstate agency, construction projects of the Port Authority are not required to comply with any building code. With respect to design and construction of the WTC towers, however, in 1963 the Port Authority instructed its consultants to prepare their designs of WTC 1 and WTC 2 to comply with the New York City Building Code (Levy 1963). Although it was not specifically stated in the letter to the architect, the 1938 edition of the Code was in effect at that time. In areas where the Code was not explicit or where technological advances made portions of the 1938 Code obsolete, the Port Authority directed the architect and consulting engineers to propose designs "based on acceptable engineering practice." The Port Authority also required the design professionals to inform the Planning Division of the WTC when such situations occurred. The Port Authority established a special WTC office that reviewed and approved plans, issued variances, and conducted inspections during construction instead of the city agencies and employees that would normally perform these duties.

The Port Authority further stated that all design concepts would be reviewed before the final design by the Chief Engineer of the Port Authority and by the appropriate New York City agencies. According to correspondence in 1975 from the architect-of-record for the WTC project, the New York City Building Department reviewed the design drawings of WTC 1 and WTC 2 in 1968 (Solomon 1975).

In 1965, the Port Authority instructed the architect and consulting engineers to revise their designs for WTC 1 and WTC 2 to comply with the second and third drafts of the New York City Building Code then being finalized and to undertake any design modifications necessary to comply with the new code provisions (Levy 1965). The new New York City Building Code (NYC BC 1968) was enacted by the City Council on October 22, 1968, approved by the Mayor on November 6, 1968, and became effective on December 6, 1968.

The Port Authority intended to lease space in WTC 1 and WTC 2 to tenants who would adapt their spaces to their own needs through a tenant alteration process. To maintain structural integrity and fire safety, the Port Authority issued a set of requirements for the alteration process. The first edition of the *Tenant Construction Review Manual* was issued in 1971, shortly after the first tenants occupied WTC 1 in December 1970 and before initial occupancy of WTC 2 in 1972. The manual contained the technical criteria to be used in planning alterations (architectural, mechanical, electrical, fire protection, and so forth) to Port Authority facilities. Included were applicable standards to be used by tenants and their agents and review criteria to be used by the Engineering Department of the Port Authority. Alteration designs were to be completed by registered design professionals, and at the completion of the work, as-built drawings were to be submitted to the Port Authority. The 1968 New York City Building Code was referenced, and specific code provisions were referenced in various checklists. The review manual was updated in 1979, 1984, 1990, and 1997, at which times changes that had been made to the New York City Building Code were incorporated. In 1998, the manual was replaced by the *Architectural and Structural Design Guidelines, Specifications, and Standard Details*, which dealt specifically with alterations to WTC 1 and WTC 2.

Unlike WTC 1 and WTC 2, which were developed and owned by the Port Authority, WTC 7 was developed on land owned by the Port Authority, but the building was owned by Seven World Trade Company and Silverstein Development Corporation, General Partner. It was designed and constructed as a “Tenant Alteration” project of the Port Authority. When WTC 7 was designed in the mid-1980s, the 1968 New York City Building Code with amendments was in effect. The Project Specifications for WTC 7 issued in 1984 required that the structural steel be designed in accordance with the then current New York City Building Code.

A.1.1 The New York City Building Code

The New York City Building Code is part of the Administrative Code of New York City. It is amended from time to time by Local Laws to improve safety requirements or to incorporate technological advances. New York City Council Members, at the request of any person or group, can introduce a bill to the Council for the purpose of amending the Building Code requirements. When passed by the Council and approved by the Mayor, the bill becomes a Local Law. Seventy-nine Local Laws were adopted between 1969 and 2002 that modified the 1968 Building Code. For example, Local Laws 5, 16, and 86 made important modifications to fire protection and life safety features of the 1968 Building Code.

To aid the implementation of and to clarify building code requirements, New York City issues “rules.” These rules are initiated typically by City Government offices such as the Department of Buildings and the Department of Environment. These rules do not require enactment by the City Council, and new rules issued by the Building Commissioner can be put into effect expeditiously. The rules are part of the Building Code, and are required to be complied with for design, construction, and maintenance of buildings.

The 1968 New York City Building Code includes “Reference Standards.” These include standard test methods published by the ASTM International, or design standards published by other consensus-based organizations. These reference standards may include modifications to the provisions in the published standards, or they may be stand-alone requirements developed by New York City.

A.1.2 Scope of Appendix

The 1968 New York City Building Code (NYCBC 1968) is compared with four other codes. They are: the 1964 New York State Building Construction Code (NYSBC 1964); the 1965 BOCA Basic Building Code (BOCA/BBC 1965); the 1967 Municipal Code of Chicago Relating to Buildings (MCC 1967); and the 2001 edition of the New York City Building Code (NYCBC 2001)

The 1964 New York State Building Construction Code was selected for comparison, as it would have been a governing building code outside the New York City limits. The 1965 BOCA Basic Building Code was selected, as it was typically adopted by local jurisdictions in the northeastern region of the U.S. The 1968 New York City Building Code is compared with the 1967 Municipal Code of Chicago to see whether there are any substantial differences in the structural and fire safety requirements of the two codes. In the late 1960s and early 1970s, several tall buildings were built in Chicago including the Sears Tower (110 stories) and the John Hancock Tower (100 stories). The 2001 edition of the New York City Building Code is compared with the 1968 version to examine the extent to which Local Laws have modified the code provisions, and in most cases, is only addressed in areas where changes have occurred between the two versions.

A provision by provision comparison was made between the 1968 New York City Building Code and these four codes. The code provisions that were compared are limited to the requirements related to structural stability, active and passive fire safety, and emergency egress. This appendix presents a summary of substantial differences noted in the comparison. This summary focuses on the following topics:

- Loads to be considered in the design of buildings;
- Requirements for materials, design, and construction;
- Fire protection requirements; and
- Egress requirements.

With respect to structural stability, no Local Law other than Local Law 17 (seismic provisions for new construction) has been adopted that modified the structural requirements of the 1968 New York City Building Code. Hence comparison between the structural requirements of the 1968 and 2001 New York City Building Code is not discussed here, with the exception of earthquake loads.

A.2 LOADS

A key aspect of any structural design is the loading that the structure is intended to support. Building codes provide minimum values for the different types of loads that are considered in typical building designs. The designer is permitted to use larger values for these loads, but is not permitted to use smaller values without approval by the building official. This section compares the specified loads in the codes that were compared. Similarities and differences are noted.

A.2.1 Dead Loads

Dead loads refer to loads that are permanently present in a building. They include, for example, the weight of the structural components, the weights of permanent partitions, the weights of floor and wall finishes, and the weights of service equipment that is part of the building (elevator equipment, plumbing, electrical, heating, air conditioning, and ventilation systems). Weights of the structural components are computed from the sizes of the members and the densities of the material, and codes typically provide default density values for different materials. The dead loads of partitions and walls are typically prescribed in terms of weight per unit area of wall, and the weight per unit length of wall or partition is determined from these prescribed values and the heights of the partitions or walls. Floor finishes and ceilings are typically specified in terms of a uniform load per unit area of floor or ceiling. Table A–1 gives examples of the minimum values of dead load prescribed in Referenced Standard RS 9-1 in the 1968 New York City Building Code and in Appendix J of the 1965 BOCA Basic Building Code. There are no corresponding provisions in the 1964 New York State Building Construction Code or the 1967 Municipal Code of Chicago. Typically, the designer is permitted to use weights based on available data that are greater than the specified minimum values, but the designer is not permitted to use lower values without approval of the Code Official.

Table A–1. Examples of dead loads given in NYC Building Code and BOCA Code.

	NYC	BOCA
Walls and Partitions		
Hollow concrete block – 8 in. thick	53 psf	50 psf
Clay tile, nonload bearing – 8 in. thick	34 psf	36 psf
Plaster partition, metal studs & lath, gypsum plaster both sides	18 psf	18 psf
Floor Finishes		
Resilient flooring	2 psf	2 psf
Hardwood flooring 7/8 in. thick (1 in. for BOCA)	4 psf	4 psf
Cement, 1 in. thick	12 psf	12 psf
Ceilings		
Suspended acoustical tile	2 psf	–
Suspended metal lath and gypsum plaster	9 psf	10 psf
Miscellaneous Materials		
Marble	168 pcf[a]	168 pcf
Concrete (normal density stone or gravel)	144 pcf	144 pcf
Reinforced concrete (normal density)	150 pcf	150 pcf

a. Note that the units in the 1968 New York City Building Code are given incorrectly as "psf."

According to the 1968 New York City Building Code, weights from service equipment (plumbing stacks, piping, heating, ventilating, and air conditioning (HVAC), etc.) are to be included in the dead load (C26-901.2)[1]. The weight of equipment that is part of the occupancy of a given area is to be considered as live load (see next section). The 1964 New York State Building Construction Code and the 1967 Municipal Code of Chicago do not have a provision in this regard. The 1965 BOCA Basic Building Code has a similar provision but without citing specific types of service equipment as in the New York City Code.

The 1968 New York City Building Code requires that weights of partitions be considered in two ways: (1) using line loads at locations shown on plans or (2) using the equivalent uniform load given in Reference Standard RS 9-1. The stipulated equivalent uniform load depends on the partition weight, for example, if a partition weighs 201 plf to 350 plf, it may be taken into account by designing for a uniform load of 20 psf. The uniform loading approach, however, is not permitted in certain situations for which actual partition weights must be used. Equivalent uniform loads must be used in areas where the locations of partitions are not shown on plans, or in areas where partitions can be relocated. The 1964 New York State Building Construction Code does not have a specific provision in this regard. The 1967 Municipal Code of Chicago prescribes a minimum partition load of 20 psf. The BOCA Basic Building Code requires consideration of the actual weight of the partitions or an equivalent uniform load of at least 20 psf.

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1 Refers to section number in the 1968 New York City Building Code.

A.2.2 Live Loads

Live loads are those resulting from the use and occupancy of the building, and include loads such as weights of occupants, furniture, filing cabinets, safes, mechanical equipment, and other items that the structure is called upon to support. Live loads are specified in terms of weight per unit of floor (or roof) area or in terms of concentrated loads. The values specified in codes are based largely on load survey data, experience, and judgment.

Floor Live Loads

In general, values of minimum uniformly distributed live loads specified in codes are organized on the basis of use or occupancy of spaces and there is no consistency in the names of these use categories. Thus comparison between codes is not straightforward. Table A–2 gives some examples of minimum uniformly distributed live loads for floors. It is seen that there is general agreement in the values of these selected minimum uniform live loads specified by the four codes.

Table A–2. Examples of minimum uniformly distributed live loads

	1968 NYC	1964 NYS	1967 Chicago	1965 BOCA
Office space	50 psf	50 psf	50 psf	50 psf
Restaurant	100 psf	100 psf	–	100 psf
Lobbies	100 psf	100 psf	100 psf	100 psf
Stairways	100 psf	100 psf	75–100 psf[a]	100 psf
Rest rooms	40 psf	60 psf	–	–
Hospital operating room	60 psf	60 psf	40 psf	60 psf
School classroom	40 psf	60 psf	40 psf	–

a. Depends on occupancy, for example, 75 psf for business, 100 psf for schools.

The codes also specify concentrated live loads placed so as to result in maximum stresses.

Live Load Reduction

There is a low likelihood that the full design floor live loads will be present on all floors of a building at the same time. In addition, the likelihood that the complete area on any one floor is loaded with the design load decreases as the floor area increases. To account for these factors, building codes permit "live-load reductions" in calculating the design loads for primary members (columns and girders) that support the roof and floors. The codes use several methods for live-load reduction (CTB&UH 1980):

1. *Percentage Method*—In this method, the live load reduction increases by a certain percentage with increasing numbers of floors, with a limit on the maximum value of reduction (typically 50 percent).

2. *Tributary Area Method*—The live load is reduced as the accumulated tributary area that is supported by a member is increased. The limiting value depends on the ratio of live load to dead load. The type of occupancy affects whether a reduction is permitted.

3. *Live Load to Dead Load Ratio*—The permitted reduction depends on the ratio of live load to dead load, provided that the dead load is greater than the live load.

The 1968 New York City Building Code uses the tributary area method and permits the percentage method as an alternative for columns, piers, and walls. The 1964 New York State Building Construction Code and the 1967 Municipal Code of Chicago use the tributary area method for beams and girders and the percentage method for columns and walls. The 1965 BOCA Basic Building Code uses a tributary method that is similar to the New York State Code.

Figure A–1 compares the reduced live load for columns, walls, and piers on the basis of the percentage method for three of the codes. It is seen that the permitted reductions are similar with the exception of the roof and top floor, where the 1968 New York City Building Code and the 1967 Municipal Code of Chicago are more conservative (less reduction permitted) than the 1964 New York State Building Construction Code.

Table A–3 compares the reduced live loads for beams and girders for the different codes. For the 1968 New York City Building Code, the reduced value of live load for a given contributory area depends on the live load to dead load ratio, with lower values permitted for lower live load to dead load ratios. For the 1964 New York State Building Construction Code and the 1965 BOCA Basic Building Code, the values shown in the table are based on a reduction factor of 0.08 %/ft^2. The lowest reduced value, however, is limited to 40 percent or

$$100\ \% \frac{3.33\frac{L}{D} - 1}{4.33\frac{L}{D}} \tag{A.1}$$

whichever is larger, where *L/D* is the live load to dead load ratio. As the ratio of live load to dead load increases, less live load reduction is permitted. A comparison of the values in Table A–3 shows that the 1967 Municipal Code of Chicago did not permit as large a reduction in live load for the same contributory area as the other codes.

A.2.3 Wind Load

The effect of wind on buildings is taken into account by the building codes by specifying a uniform pressure to be applied horizontally to a building. These pressures are to be applied in any direction so as to obtain the most critical loading condition.

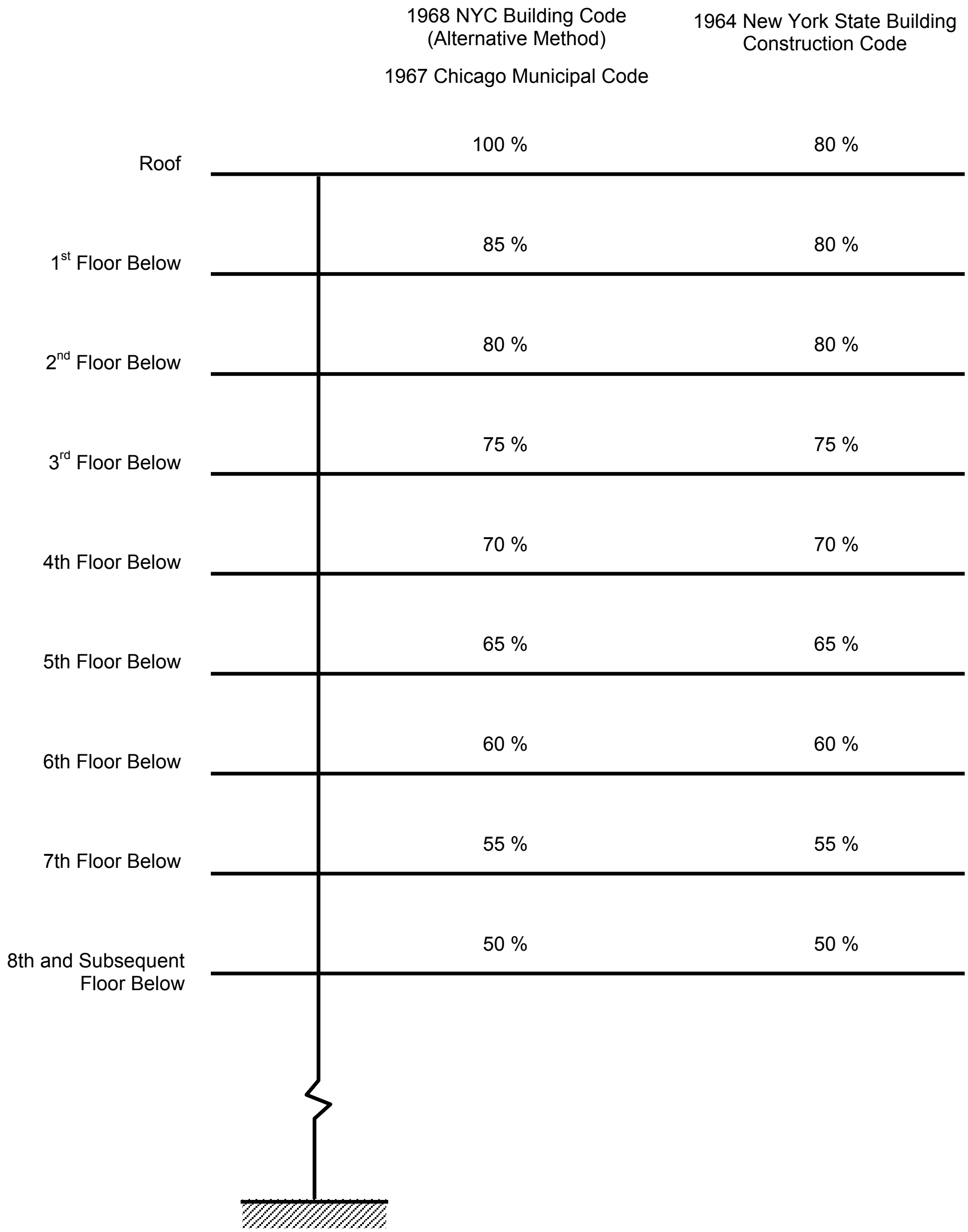

Figure A–1. Wind load pressure elevation.

Table A–3. Reduced live load for beams and girders.

Contributary Area (ft^2)	1968 NYC Building Code	1967 Chicago Municipal Code	1956 NY State and 1965 BOCA Codes
100 or less	100 %	100 %	100 %
100–149	100 %	95 %	100 %
150–199	80 % to 85 %[a]	95 %	84 % to 88 %[b]
200–299	80 % to 85 %[a]	90 %	76 % to 84 %[b]
300–449	60 % to 75 %[a]	85 %	64 % to 76 %[b]
450–599	50 % to 70 %[a]	85 %	52 % to 64 %[b]
600 and more	40 % to 65 %[a]	85 %	40 % to 52 %[b]

a. Permitted value depends on live load to dead load ratio; less reduction permitted with higher ratio.
b. The lowest value is limited to 40 percent or 100 percent (3.33 L/D –1)/(4.33 L/D), whichever is greater.

The pressure due to wind varies with the square of the wind speed, and wind speed increases with height. Thus building codes specify minimum design wind pressures that increase with elevation. The variations of pressure with height, however, are not the same among the building codes compared. Figure A–2 compares the specified wind pressure versus height relationships for the four codes that were compared. Several observations are noted:

- For buildings up to 600 ft in height, the 1964 New York State Building Construction Code prescribes the largest wind pressures.
- The 1967 Municipal Code of Chicago prescribes the lowest wind pressures for buildings up to 900 ft in height.
- The 1968 New York City Building Code and the 1965 BOCA Basic Building Code provide similar wind pressures for buildings up to 700 ft in height; for taller buildings the BOCA Code specifies larger pressures.

For a building height of 1,370 ft (the approximate heights of WTC 1 and WTC 2), the wind pressure distribution specified by the 1965 BOCA Basic Building Code would result in the largest shear force and overturning moment at the base of the building.

The 1968 New York City Building Code permits the designer to use wind pressure values, other than specified minimums, on the basis of wind tunnel tests and with approval of the building official. The following wording is provided in Section 6 of Reference Standard RS 9-5, "Minimum Design Wind Pressures."

> In lieu of the design wind pressures established in sections 1 and 2 of this reference standard, and subject to review and approval of the commissioner, design wind pressures may be approximated from suitably conducted model tests. The tests shall be predicated on a basic wind velocity of 80 mph at the 30 ft level, and shall simulate and include all factors involved in considerations of wind pressure, including pressure and suction effects, shape factors, functional effects, gusts, and internal pressures and suctions.

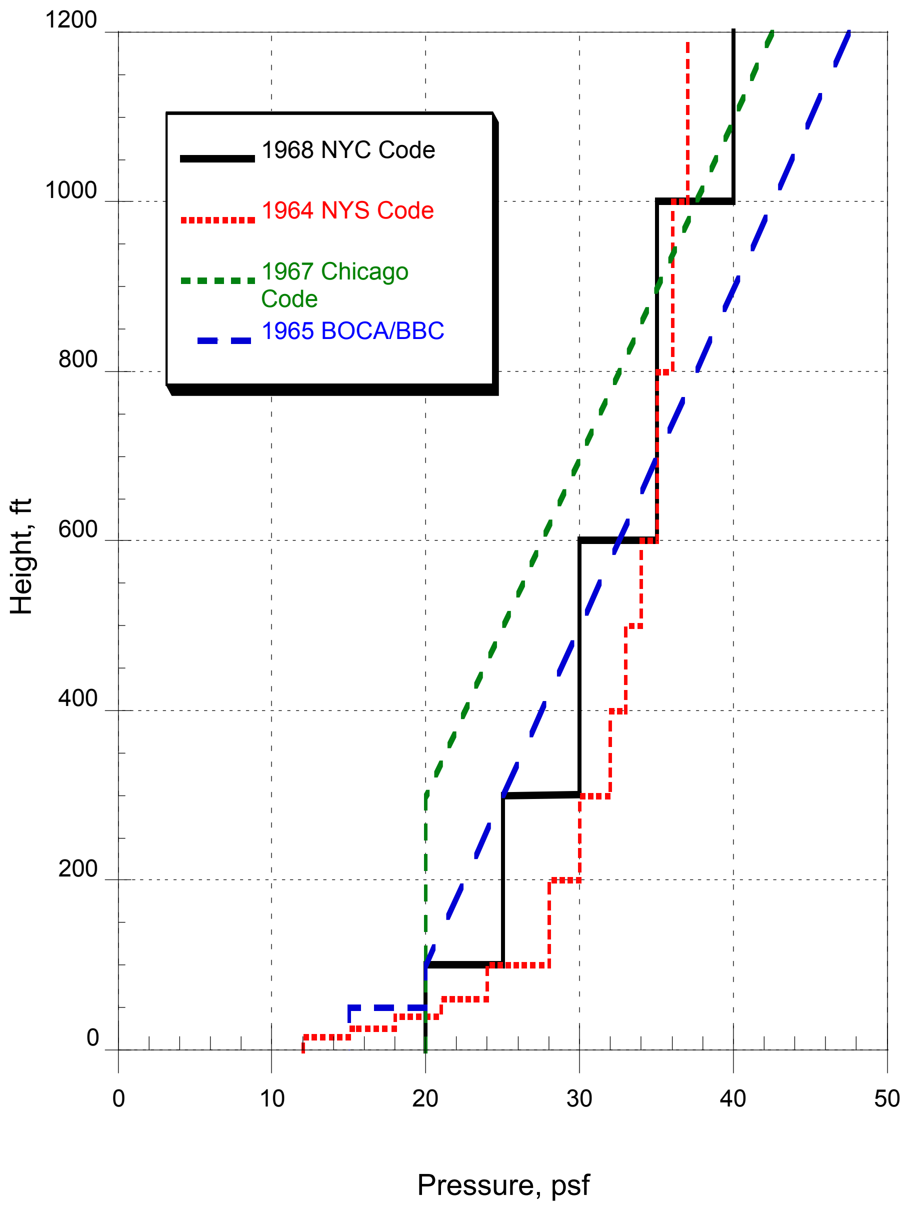

Figure A–2. Wind load pressure versus elevation.

Thus the 1968 New York City Building Code presumes a wind with a speed of 80 mph measured 30 ft above the ground. The 1964 New York State Building Construction Code, on the other hand, states that the prescribed wind loads “are based on a design wind speed of 75 mph at a height of 30 ft above grade level.” Both the 1965 BOCA Basic Building Code and the 1967 Municipal Code of Chicago do not specify the design wind speed.

A.2.4 Earthquake Load

The 1968 New York City Building Code does not have provisions for earthquake loads. Among the contemporaneous codes that were compared, only the 1965 BOCA Basic Building Code has earthquake load provisions. These are contained in Appendix K-11 of that Code and were adapted from the 1962 edition of the Uniform Building Code.

The 2001 edition of the New York City Building Code contains seismic design provisions from the 1988 edition of the Uniform Building Code (UBC 1988), including the 1990 Accumulative Supplement. These provisions were put into effect in 1996 as a result of Local Law17 (passed in 1995). Significant modifications to the 1988 Uniform Building Code were made, and described in Reference Standard RS 9-6.

One modification is to the paragraph on "Minimum Seismic Design," which is modified to read:

> The following types of construction shall, at a minimum, be designed and constructed to resist the effects of seismic ground motions as provided in this section:
>
> > new structures on new foundations;
> >
> > new structures on existing foundations; and
> >
> > enlargements in and of themselves on new foundations.
>
> Buildings classified in New York City occupancy group J-3 and not more than three stories in height need not conform to the provisions of this section. The Commissioner may require that the following types of construction be designed and constructed to incorporate safety measures as necessary to provide safety against the effects of seismic ground motions at least equivalent to that provided in a structure to which the provisions of the section are applicable:
>
> > new buildings classified in occupancy group J-3 and which are three stories or less in height; and
> >
> > enlargements in and of themselves where the costs of such enlargement exceeds sixty percent of the value of the building.

In the subdivision on "Criteria Selection" the following paragraph was added:

> Seismic Zone. The seismic zone factor, Z, for buildings, structures and portions thereof in New York City shall be 0.15. The seismic zone factor is the effective zero period acceleration for S_1 type rock.

Other significant amendments include consideration of soil liquefaction that is not to be found in the Uniform Building Code.

A.2.5 Other Loads

The 1968 New York City Building Code has provisions dealing with types of loadings not considered in the other codes that were compared. Two examples are "thermal forces" and "shrinkage." Paragraph C26-905.7 deals with thermal forces and includes the following requirement:

> …For exterior exposed frames, arches, or shells regardless of plan dimensions, the design shall provide for the forces and/or movements resulting from an assumed expansion and contraction corresponding to an increase or decrease in temperature of forty degrees F for concrete or masonry construction and sixty degrees F for metal construction….

Paragraph C26-905.8 on shrinkage includes the following requirement:

> The design of reinforced concrete components shall provide for the forces and/or movements resulting from shrinkage of the concrete in the amount of 0.0002 times the length between contraction joints for standard weight concrete, and 0.0003 times the length between contraction joints for lightweight concrete….

A.2.6 Distribution of Loads

Another topic that is contained only in the 1968 (and 2001) New York City Building Code is the distribution of loads, which is covered in Article 7 of Sub-chapter 9. Section C26-906.1 deals with vertical loads and states:

> "Distribution of vertical loads to supporting members shall be determined on the basis of a recognized method of elastic analysis or system of coefficients of approximation. Elastic or inelastic displacements of supports shall be considered and, for the distribution of dead loads, the modulus of elasticity of concrete or composition [composite] sections shall be reduced to consider plastic flow. Secondary effects, due to warping of the floors shall be considered."

Section C26-906.2 deals with distribution of horizontal forces. Because this section provides important information in the design assumptions to be used in the design of high-rise buildings, several key sections are repeated here,

> The following provisions shall apply to superstructure framing only, and shall not apply to structures wherein horizontal loads are transmitted to the foundation by staycables, arches, non-rectangular frames, or by frames, trusses, or shear walls not oriented in vertical planes.
>
> **(a) Distribution of horizontal loads to vertical frames, trusses and shear walls.** - Horizontal loads on the superstructure shall be assumed to be distributed to vertical frames, trusses, and shear walls by floor and roof systems acting as horizontal diaphragms. The proportion of the total horizontal load to be resisted by any given vertical frame, truss, or shear wall shall be determined on the basis of relative rigidity, considering the eccentricity of the applied load with respect to the center of resistance of the frames, trusses, or shear walls. For vertical trusses, web deformations shall be considered in evaluating the rigidity.

(b) Distribution of horizontal loads within rigid frames of tier buildings. - (1) ASSUMPTIONS. - The distribution of horizontal loads within rigid frames of tier buildings may be determined on the basis of a recognized method of elastic analysis or, subject to limitations in paragraph two of this subdivision, may be predicated on one or more of the following simplifying assumptions:

a. Points of inflection in beams or columns are at their midspan and midheight, respectively. The story shear is distributed to the columns in proportion to their stiffnesses.

b. The change in length of columns due to axial effects of the horizontal loads may be neglected.

c. Vertical column loads due to horizontal forces are taken by the exterior columns only, or are resisted by the columns in proportion to the column distances from the neutral axis of the bent.

(2) LIMITATIONS. -

a. For buildings over 300 ft in height, the change in length of the columns, due to the effects of the horizontal loads, shall be evaluated or the framing proportioned to produce regular movements of the successive joints at each floor so that warping of the floor system may be neglected.

b. Simplifying assumptions used in design shall be subject to approval by the commissioner for any of the following conditions or circumstances:

1. For buildings over 300 ft in height or for buildings with a height-width ratio greater than five.
2. At two-story entrances or intermediate floors.
3. Where offsets in the building occur.
4. Where transfer columns occur.
5. In any similar circumstances of irregularities or discontinuities in the framing.

A.3 MATERIALS, DESIGN, AND CONSTRUCTION

Subchapter 10 of the 1968 New York City Building Code is entitled “Structural Work” and it provides minimum requirements for materials, design, and construction of all structural elements in buildings. This summary reviews design standards, materials, load combinations, and load tests.

A.3.1 Design Standards

Design standards refer to those documents that are used to proportion the structural elements and their connections. The principal structural materials in the WTC were concrete and steel, and the design standards are those produced by the American Concrete Institute (ACI) and the American Institute of Steel Construction (AISC). The ACI produces the standard known as ACI 318, *Building Code Requirements for Reinforced Concrete,*[2] and the AISC produced the following:

- Specification for the Design, Fabrication and Erection of Structural Steel for Buildings (AISC 1963)
- Specifications for Structural Steel Buildings–ASD and Plastic Design (AISC 1989)
- Load and Resistance Factor Design Specifications for Structural Steel Buildings (AISC 1993)

Table A–4 summarizes the concrete and steel design standards adopted by the codes that were compared. The 1964 New York State Building Construction Code is a performance standard and does not adopt design standards by reference. Thus at the time the WTC Towers were being designed, the other two codes (Chicago and BOCA) referenced the same concrete and steel design standards as the New York City code.

Table A–4. Design standards for concrete and steel.

	1968 NYC Code	2001 NYC Code	1967 Chicago Code	1965 BOCA Code
Concrete	ACI 318-63	ACI 318-89	ACI 318-63	ACI 318-63
Steel	AISC 1963	AISC 1989 AISC 1993	AISC 1963	AISC 1963

The 1963 edition of ACI 318 permits reinforced concrete members to be designed by either the working stress (or allowable stress) method or by the ultimate strength method. The 1963 AISC specification, on the other hand, is based on allowable stress design. The design method affects the loads used in the design calculations.

A.3.2 Load Combinations

The loads prescribed by the codes are used in different combinations to assess the governing design condition. The codes distinguish between sustained loads and loads of short duration or infrequent occurrence. For allowable stress design, two approaches are used for dealing with these two categories of loads, as will be discussed. For ultimate strength design, the prescribed loads are multiplied by specified load factors. In either case, the designer considers all applicable load combinations and determines the most critical condition, which becomes the design basis for a particular element.

---

[2] In 1999, the title was changed to *Building Code Requirements for Structural Concrete.*

Allowable Stress Design

The 1968 New York City Building Code defines two categories of loads:

1. Basic loads, which include dead load, live load, and reduced live load where applicable; and

2. Loads of infrequent occurrence, which include wind load, thermally induced load, shrinkage induced load, and unreduced live load where live load reduction is permitted.

Stresses in structural elements cannot exceed the allowable values specified in the referenced design standards under the following load combinations:

- The sum of the basic loads multiplied by a factor equal to 1;

- The factored sum of one or more basic loads and one load of infrequent occurrence, where the load factor equals 0.75;

- The factored sum of one or more basic loads plus two or more loads of infrequent occurrence, where the load factor equals 0.6.

The 2001 New York City Building Code is similar with the exception that it includes earthquake load as another load of infrequent occurrence.

The other Codes that were compared use a different approach for dealing with loads of infrequent occurrence. The 1964 New York State Building Construction Code states that stress due to wind load may be ignored if it less than 1/3 of the stress due to dead load plus imposed load excluding wind load. If the stress due to wind load exceeds this limit, the allowable stress for the material is permitted to be increased by 1/3.

The 1967 Municipal Code of Chicago uses a similar approach and states: "For combined stresses due to dead, live, and wind load, the allowable stresses in materials may be increased 1/3, provided the section thus determined is at least as strong as that required for dead and live load alone. Snow load shall be considered a live load."

The 1965 BOCA Basic Building Code is similar except that wind load or earthquake load is considered along with dead load and live load (including snow load). The same 1/3 increase in allowable stress is permitted under wind or earthquake load. The BOCA Code also explicitly states that wind load is permitted to be neglected if it results in stress less than 1/3 the stress due to dead load plus live load.

Ultimate Strength Design

In the 1960s, ultimate strength design was standardized only for reinforced concrete. As shown in Table A–4, the three codes from the 1960s referenced ACI 318-63, which include the following load combinations to establish the design loads (U) for structural members:

1. For structures where wind and earthquake loads may be neglected, $U = 1.5\ D + 1.8\ L$.

2. For structures where wind load must be included, U = 1.25 (D + L) or U = 0.9 D+ 1.1 W, whichever produces the most unfavorable condition for the member.

3. For structures where earthquake loading is included, E shall be substituted for W in condition 2.

4. In structures where effects of shrinkage and temperature are included, the effects of such items shall be considered on the same basis as the effects of dead load.

The 2001 New York City Building Code refers to ACI 318-99, which includes many more load combinations to be considered. These are as follows:

1. For all structures, U = 1.4 D + 1.7 L.

2. For structures where wind load must be included, U = 0.75[1.4 D + 1.7 L + 1.7 W)] or U = 0.9 D + 1.3 W, whichever produces the most unfavorable condition for the member.

3. For structures where resistance to earthquakes must be included, the load combinations of condition 2 are used with 1.1 E substituted for W.

4. For structures where resistance to earth pressure (H) must be included, U = 1.4 D + 1.7 L + 1.7 H or 0.9 D + 1.7 H, whichever produces the most unfavorable condition.

5. For structures where resistance to fluid pressure (F) must be included, U = 1.4 D + 1.7 L + 1.4 F or 0.9 D + 1.7 F, whichever produces the most unfavorable condition.

6. For structures where resistance shrinkage and temperature (T) must be included, U = 0.75 (1.4 D + 1.4 T + 1.7 L) > 1.4 (D + T).

7. For structures where resistance to impact must be taken into account, such effects shall be included with live load L.

A.3.3 Alteration of Existing Buildings

The compared codes have provisions to address code compliance when existing buildings are altered. The provisions of all codes, other than the 1964 New York State Building Construction Code, are broadly similar. In general, whether the altered building or only the alternations need to comply with code requirements depends on the ratio of alterations to the total building expressed either in terms of cost or dimensions. When the ratio is low, even the alterations may not have to be in compliance with the code, provided stipulated conditions are met. The 1964 New York State Building Construction Code, however, requires that any addition or alteration regardless of building value shall be made in conformity with that code. It is silent as to the structure being altered. Table A–5 summarizes code provisions related to alterations.

Table A–5. Compliance requirements for alterations.

Code	Provisions
1968 New York City Building Code	**Alterations exceeding 60 percent of building value (in any 12-month period):** The entire building shall be made to comply with the requirement of the code. **Alterations between 30 percent and 60 percent of building value:** Only those portions of the building altered shall be made to comply with the requirements of the code. **Alteration under 30 percent of building value:** Those portions altered may, at the option of the owner, be altered in accordance with the requirement of the code, or altered in compliance with their previously required condition and with the same or equivalent materials and equipment, provided the general safety and public welfare are not thereby endangered.
2001 New York City Building Code	Same as 1968 Code, except that wording for alterations **less than 30 percent** of building values was changed to: "those portions of the building altered may, at the option of the owner, be altered in accordance with the requirements of this code, or altered in compliance with the applicable laws in existence prior to December sixth, nineteen hundred sixty-eight, provided the general safety and public welfare are not thereby endangered." In addition, certain alterations are required to conform to the code regardless of magnitude or cost. These include, among others: Alterations to standpipes, sprinklers, or interior fire alarm and signal systems; Alterations to equipment for heating or storing water; Sprinkler, alarm protection, and emergency lighting requirements for places of assembly.
1964 New York State Building Construction Code	**Addition or alteration:** Any addition or alteration, regardless of cost, made to a building shall be made in conformity with applicable regulations of the code.
1967 Municipal Code of Chicago	**More than 50 percent:** Such buildings and structures shall be made to conform to all requirements of the code that are applicable to new buildings and structures. **25 percent to 50 percent:** All new constructions shall conform to the requirements of the code for new buildings or structures of like area, height and occupancy. **25 percent or less:** Certain exceptions can be made that allow the use of materials that conform to the strength and fire resistance for the materials with which the building is constructed. Otherwise, all new construction shall conform to the requirements of this code for a new building.
1965 BOCA Basic Building Code	"In the reconstruction, repair, extension or alteration of existing buildings, the allowable working stresses used in design shall be as follows: 1. **Building extended:** If altered by an extension in height or area, all existing structural parts affected by the addition shall be strengthened where necessary and all new structural parts shall be designed to meet the requirements for buildings hereafter erected. 2. **Building repaired:** When the uncovered structural parts are found unsound, such parts shall be made to conform to the requirements for buildings hereafter erected. 3. **Existing live load:** When an existing building heretofore approved is altered or repaired within the limitation prescribed in Section 106.3 (alteration under 50 percent) and 106.4 (alteration under 25 percent), the structure may be designed for the loads and stresses applicable at the time of erection, provided that public safety is not endangered. 4. **Posted live load:** May be posted for original approved live loads."

A.3.4 Materials and Methods of Construction

The compared codes have requirements for the materials and construction methods. Each code makes distinctions in materials and methods that depend on the nature of inspection and conformance with standards.

The 1968 New York City Building Code prescribes testing and inspection requirements for all materials, assemblies, forms, and methods of construction. A distinction is made between materials and methods subject to "controlled inspection" and those that are not subject to controlled inspection. Materials and methods subject to controlled inspections "shall be inspected and/or tested to verify compliance with code requirements." In general, activities related to controlled inspections "shall be made and witnessed by or under the direct supervision of an architect or engineer retained by or on behalf of the owner or lessee, who shall be, or shall be acceptable to, the architect or engineer who prepared or supervised the preparation of the plans." On the other hand, materials and methods not designated for controlled inspection "shall be inspected and/or tested to verify compliance with code requirements by the person superintending the use of the material or its incorporation into the work…"

The 1968 New York City Building Code provides tables to indicate which materials and methods are subject to controlled inspections and which are not. Table A–6 includes excerpts from the requirements for inspection of materials and assemblies. A footnote to the table in the code states that "All structural materials and assemblies subject to controlled inspection shall be tested and/or inspected at their place of manufacture and evidence of compliance with the provisions of this subchapter shall be provided as stipulated in sub-articles 1003.0 through 1011.0." Table A–7 is an excerpt of the inspection requirements for methods of construction. A footnote to the companion table in the code states that "All construction operations designated for controlled inspection shall be inspected by the architect or engineer designated for controlled inspection during the performance of such operation."

The 1968 New York City Building Code required that the installation of "sprayed-on fire protection" of structural members (except those encased in concrete) be subjected to controlled inspection requirements, as defined above. There were, however, no specific provisions on what testing was required.

The 1964 New York State Building Construction Code and the 1965 BOCA Basic Building Code make distinctions between "controlled" and "ordinary" materials in reference to establishing allowable stresses. For example BOCA defines "controlled materials" as those that are "certified by an accredited authoritative agency as meeting accepted engineering standards for quality." Ordinary materials are those that do not conform to the requirements for controlled materials.

The 1967 Municipal Code of Chicago specifies that all materials and methods used in the design and construction of buildings shall be classified as "controlled materials" or "ordinary materials." According to the Chicago Code, "controlled materials" means a building, structure, or part thereof, which has been designed or constructed under the following conditions: (a) All controlled materials must be selected or tested to meet the special strength, durability and fire resistance requirements upon which the design is based. (b) The design, preparation of working drawings, including details and connections, the checking and approval of all shop and field details and the inspection of the work during construction shall be under the supervision of a registered architect or structural engineer (Section 69-3.1).

Table A–6. Excerpts of inspection requirements for materials and assemblies in 1968 New York City Building Code.

Material	Elements Subject to Controlled Inspection	Elements Not Subject to Controlled Inspection
Steel	None	All structural elements and connections
Concrete	Materials for all structural elements proportioned on the basis of calculated stresses 70 percent or greater, of basic allowable stresses. See Section 1004.0 for specific requirements relating to “quality control of materials and batching.”	(1) All materials for all structural elements proportioned on the basis of calculated stresses less than 70 percent or greater of basic allowable values. (2) Concrete materials for: (a) Short span floor and roof construction proportioned as per section 1004.8. (b) Walls and footings for buildings in occupancy group J-3. (3) Metal reinforcement.

Table A–7. Excerpts of inspection requirements for methods of construction in 1968 New York City Building Code.

Material	Operations Subject to Controlled Inspection	Operations Not Subject to Controlled Inspection
Steel	(1) Welding operations and the tensioning of high strength bolts in connections where the calculated stresses in the welds or bolts are 50 percent or more of basic allowable values. (2) Connection of fittings to wire cables for suspended structures, except where cables together with their attached fittings are proof-loaded to not less than 50 percent of ultimate capacity.	(1) Welding operations and the tensioning of high strength bolts in connections where the calculated stresses in the welds or bolts are less than 50 percent of basic allowable values. (2) All other fabrication and erection operations not designated for controlled inspection.
Concrete	Except for those operations specifically designated in this table as not subject to controlled inspection, for all concrete, the operations described in section 1004.5(a) shall be subject to controlled inspection.”	(1) All operations relating to the constriction of members and assemblies (other than prestressed concrete) which involve the placement of a total of less than 50 cubic yards of concrete and wherein said concrete is used at levels of calculated stress 70 percent or less of basic allowable values. (2) placing and curing of concrete for all: (a) short span floor and roof construction as per section 1004.8. (b) Walls and footings for buildings in occupancy group J-3. (3) Size and location of reinforcement for walls and footings in occupancy group J-3. (4) All other operations not described in Sections C26-1004.5(a).

A.3.5 Stability, Bracing, and Secondary Stresses

The 1968 and 2001 New York City Building Code are the only codes of those compared that include provisions for *stability*, *bracing*, and *secondary stresses*. The provisions are the same in the two editions of the code. Stability, in this case, refers to resistance to sliding or overturning of the building on its foundation. The New York City Building Code requires a factor of safety of 1.5 against failure by sliding or overturning. The required stability is to be provided solely by the dead load plus any permanent anchorage that is provided. Bracing refers to lateral support to prevent buckling of compression members (columns and walls). The New York City Building Code requires that the bracing be proportioned to resist a load of at least 2 percent of the total design compression load in the braced member plus any transverse shear load on the bracing member. Secondary stresses refer to stresses associated with transverse deflection of a member. In trusses, for example, secondary stresses arise because joints are not true pins and some bending is introduced, which results in transverse displacements of the individual elements. The New York City Building Code requires that secondary stresses in trusses be considered in designing the size of the individual elements.

A.3.6 Deflection Limitations

All five codes contain limits on vertical deflections of floor and roof assemblies. Except for the New York City Building Codes (both the 1968 and 2001 versions), the deflection limits relate to crack formation of plastered building components. The deflection is limited 1/360 of the span for plastered members and 1/240 of the span for non-plastered members. The New York City Building Codes refer to the reference standards for deflection limits in addition to the 1/360 of the span limit. For concrete members, ACI 318-63 specifies limits for both short- and long-term deflections of beams and one-way slabs. For steel members, the 1963 AISC Specification specifies deflection limits to avoid damage to plastered ceilings and to limit deflections of flat roofs.

A.3.7 Load Tests

Building codes generally allow load tests to ascertain the adequacy of load carrying capacity of structural members. Specifically building codes allow load tests or tests of in-place materials:

- To verify adequacy of structural design for a member or an assembly,
- To verify adequacy of partially completed construction,
- To prequalify structural members or assemblies before used in service,
- To verify adequacy of questionable completed structure, and
- To determine concrete strength by means of core tests.

The New York City Building Codes have provisions to cover all five categories. The New York State Code has provisions for (1) and (4). The Chicago Municipal Code has provisions for (1), (4) and (5). The BOCA/Basic Building Code has provisions for (1) and (2).

A.4 FIRE SAFETY

A.4.1 Fire Protection

As mentioned in A.1, in 1965, the Port Authority directed that the design of the WTC towers be updated to conform to the second and third drafts of the 1968 New York City Building Code then under development. However, since it was not known which proposals in the second and third drafts would be adopted into the final 1968 code, the strategy was to identify any proposed design provision that differed from the 1938 code requirement as a variance to be specifically approved by the Port Authority (Kyle 1966a and Kyle 1966b). The Port Authority established the World Trade Department, a special Port Authority office, to review and approve plans, to issue variances, and to conduct inspections during construction.

The 1968 New York City Building Code contained detailed fire safety provisions on a number of topics not addressed in the other codes of the time, most of which appeared in these other codes at later times. For example, while the contemporaneous codes contained requirements for flame spread ratings for interior finish materials, the 1968 New York City Building Code also included requirements for “smoke developed" ratings that did not appear in other codes until later.

As stated in Section A.1.1, the New York City Building Code is amended by “Local Laws” (LL) and refined or interpreted by administrative orders issued by the Building Commissioner. While there were some 79 Local Laws adopted between 1969 and 2002 that modified the 1968 code, those that contained significant modifications to fire protection and life safety requirements include LL54/1970, LL5/1973, LL26/1975, LL55/1976, LL33/1978, LL41/1978, LL84/1979, LL86/1979, LL16/1984 and LL16/1987. Of particular importance in this group are LL5/1973 (and LL86/1979 that changed the compliance dates for LL5/1973) and LL16/1984 because some of their provisions applied retroactively to existing office buildings.

A.4.2 General Code Provisions for Fire Safety

Fire safety of building construction is generally regulated through limits placed on the height and the area per floor as a function of the type and degree of fire resistance of materials used in the structural elements. These material characteristics are categorized as *types of construction,* e.g., Type I through V, and the associated limits are contained in “*heights and areas*” tables that are a cornerstone of most (prescriptive) building codes, worldwide.

The intent of building height limits is to restrict taller buildings to non-combustible structural members with the greatest fire resistance (as measured in the ASTM E 119 test method). The primary concern with combustible structural members is that they can become ignited by an exposing fire and can continue to burn (often in concealed spaces) even after the exposing fire has been extinguished, leading to collapse.

The other important height factor is the definition of a high-rise building. This is generally based on the height above which fire department ladders will not reach, requiring that fires be fought from inside. An interior attack is limited to hand-held hoses supplied from standpipes and working from interior stairways. Traditionally, high-rise buildings have been defined as those that exceed 75 ft or 6 stories above grade in height, but some newer codes increase this height to 100 ft, as modern fire department ladders are longer.

The intent of area limits is generally to limit property risk and to limit the size (area involved on any floor) of the fire to that which can be dealt with by the fire department with the number of people and equipment typical of an initial response.

A.4.3 Occupancy Classification

The building codes define categories of occupancy (which may have more than one sub-class). The group designations vary in different codes, the ones presented here are those used in the New York City Building Code. These are:

- High Hazard (Group A)
- Storage (Groups B-1 and B-2)
- Mercantile (Group C)
- Industrial (Group D-1 and D-2)
- Business (Group E)
- General Assembly (Group F-1 through F-4)
- Educational (Group G)
- Institutional (Groups H-1 and H-2)
- Residential (Groups J-1 through J-3)
- Miscellaneous (Group K)

Building codes use occupancy as a surrogate for risk factors that determine the level of performance needed. For example, occupancy is determined by a combination of factors such as types and quantity of combustible contents, common ignition sources, and typical occupant characteristics. Business occupancies (which includes office buildings) are considered among the lowest risk because they typically contain grades of furniture that constitute relatively low combustible loads, few ignition sources, and a population that is predominately adult, in good physical and mental condition (e.g., not using alcohol), and not sleeping. The most risky occupancies are High Hazard, in which are found highly flammable, toxic, or explosive materials, and Institutional (e.g., hospitals and prisons) in which occupants are likely to be incapable of unassisted egress.

A.4.4 Construction Classification

The model building codes classify building constructions into different "Types." Although there are some variations in categories, they are reasonably consistent.[3] The main categories are Type 1 (fire resistive), Type 2 (non-combustible), Type 3 (combustible), Type 4 (heavy timber) and Type 5 (ordinary).

Types 1 and 2 are constructed with non-combustible exterior and interior bearing walls and columns. Fire resistance ratings (see A.4.5) are greatest for Type 1, and Type 2 is any (non-combustible) construction not meeting Type I requirements. Type 3 is where exterior bearing walls are non-combustible and interior bearing walls and some columns may employ approved combustible materials. Type 4 is known as *heavy timber,* which utilizes large, solid cross section wooden members such as in post and beam construction. Type 5 is traditional wood frame construction. Common non-combustible structural elements use steel or reinforced concrete. Combustible structural elements are usually made of solid- or engineered-wood and laminates.

Combustibility of the materials in a structural element is determined in ASTM E 136 in which the material is placed in a furnace at 750 ºC (1,380 °F), which is a "typical" fire temperature. Some minor surface burning (e.g., from paint or coatings) is allowed in the first 30 s but there cannot be any significant energy release as indicated by more than 30 ºC (54 ºF) increase in the furnace temperature, and the test specimen cannot lose more than half its initial mass. Materials that pass are designated non-combustible and the rest are combustible.

Within each construction type, there are several sub-categories determined by the fire resistance ratings of the columns, beams, and floor supports. In some codes these sub-categories are identified by letters following the type (e.g., 1B or 3A) or by a set of three numbers that represent the fire resistance required (in hours) of the columns, beams, and floors, respectively (e.g., Type 1 [3,3,2]).

For unsprinklered office buildings, the following construction classes are permitted in the five building codes reviewed.

- Type 1A and 1B—NYC BC 68, NYS BC 64, BOCA/BBC 65 (Unlimited height)
- Type 1A, 1B, 1C, 1D—NYC BC 01 (Height limited to 75 ft)
- Type 1A only—Chicago BC 67 (Unlimited height)

It is noted that the 1938 New York City Building Code did not include Type 1B construction for office occupancies. The reasons for the inclusion of Type 1B construction for office occupancies into the 1968 New York City Building Code are not recorded (recordkeeping in the codes and standards development process was very poor prior to the Hydrolevel vs. ASME Supreme Court decision in 1982). The codes then and now tend to follow each other as champions of changes to one code usually try to change all of the codes. The 1950 edition of the Basic Building Code (BOCA) included a Type 1B construction class with unlimited height and area for business and low hazard storage occupancies without sprinklers. Among other model codes, the Standard Building Code (1946-47 edition, SBCCI) had a Type 2

[3] Construction type definitions varied among the model codes until an effort was expended in the 1970s by the Board for the Coordination of the Model Codes (BCMC) to eliminate unnecessary differences.

construction similar to Type 1B for business occupancies and buildings more than 80 ft in height, the National Building Code (1934 edition, NBFU) had a semi-fireproof similar to Type 1B for buildings above 75 ft, and the Uniform Building Code (1927 edition, ICBO) had a Type 2 similar to Type 1B for buildings above 75 ft.

The Basic Building Code (BOCA) would be expected to have the strongest influence on New York City since BOCA was the regional code used in the Northeast U.S. This may be why Type 1B construction was included in the 1968 New York City Building Code.

Mandatory sprinkler requirement for new high-rise buildings was first introduced in the New York City Building Code in 1984 (by Local Law 16), in BOCA in 1984, and in the Chicago building code (which allows a compartmentation alternative) in 1975. Before Local Law 16 was adopted, the 1968 New York City Building Code permitted Type 1A, 1B, 1C, and 1D construction for sprinklered office buildings of unlimited height. In the 2001 New York City Building Code, the minimum permitted construction classification for office buildings of unlimited height is Type 1C.

A.4.5 Fire Resistance of Structural Elements

The structural elements of a building are protected against failure in fire for a specified period as determined in the ASTM E 119 test. The intent of the fire rating requirements is for the structure as a minimum to withstand design loads (including fire) without local structural collapse until occupants can escape and the fire service can complete search and rescue operations.

Fire resistance requirements in the building codes are greatest for structural members that are essential to the stability of the building as a whole. These include columns and other major gravity load carrying members that connect directly to columns such as girders and trusses.

For various construction classes, the building codes specify different fire resistance ratings. The building codes reviewed specify fire resistance ratings for high-rise office occupancies as follows:

- Type 1A
  - Columns: 4 h (supporting more than one floor)
  - Beams: 3 h (floor construction)
- Type 1B
  - Columns: 3 h (supporting more than one floor)
  - Beams: 2 h (floor construction).
- Type 1C (for sprinklered buildings only)
  - Columns: 2 h (supporting more than one floor)
  - Beams: 1 ½ h (floor construction).

The choice among permitted construction classes for a particular building is made by the architect and/or the owner. Thus, an unsprinklered high-rise office building that was designed according to the 1968 version of the New York City Building Code could follow either Type 1A or 1B, and if designed subsequent to the passage of Local Law 16/1984 a high-rise office building would have to be sprinklered but it could follow Type 1C as a minimum classification. Similar reductions in the minimum required fire resistance ratings for sprinklered buildings are found in all national model building codes over this period as requirements for fire sprinklers, especially in high-rise buildings, have become common.

Type 1B, and eventually Type 1C, construction was permitted for high-rise office occupancies because this occupancy is considered low risk. Most other use groups in high-rise buildings were restricted to Type 1A, which is the construction type with the maximum structural fire protection defined in these codes.

Compartmentation and Sprinklers

Section 6 of Local Law 5 adopted by New York City in 1973, required the subdivision of unsprinklered space in new office occupancies and in existing offices over 100 ft in height by fire rated partitions. Local Law 5 was challenged in the courts and was eventually upheld, although the original compliance dates were amended by Local Law 86 (1979) so that full compliance was required by February 7, 1988.

After the passage of Local Law 5, the Port Authority implemented a program to retrofit sprinklers and to offer tenants the option of sprinklering or compartmentation consistent with Local Law 5 provisions. Sprinklering of WTC 1 and WTC 2 was undertaken in three phases: Phase 1 was the sprinklering of below grade spaces completed with the original construction. Phase 2 was begun after Local Law 5 was adopted and included the installation of sprinkler risers and other infrastructure, and the installation of sprinklers in corridors, storage rooms, lobbies, and smaller tenant spaces for tenants not selecting the compartmentation option. Phase 3 involved sprinklering the remaining tenant spaces, initially as tenants changed, and later on negotiated schedules. This process was underway when in 1984 Local Law 16 was adopted, which required sprinklers in new high-rise buildings including offices. Thus all floor spaces by February 8, 1988, had to either be subdivided in accordance with the compartmentation requirement or sprinklered. A 1997 report states that there were four floors and the sky lobbies (all in WTC 1) left to be sprinklered, and that the installation of sprinklers at these floors was underway (Coty 1997). In an October 1999 report, it is stated that sprinklering of the tenant floors was completed and sprinklering of the sky lobbies was “currently underway” (PANYNJ 1999).

Summary

Table A–8 summarizes key fire safety requirements for business occupancy in high-rise buildings (greater than 75 ft) as stipulated in the codes that were compared. In addition, the provisions from the 1938 New York City Building Code are provided for comparison. It is seen that, overall, the 1968 New York City Building Code was in accord with contemporaneous codes. Exceptions are the permitted construction classes and minimum fire ratings, which were more restrictive in the 1967 Municipal Code of Chicago.

Table A–8. Summary of fire safety provisions for business occupancy in high-rise buildings (> 75 ft).

	1938 NYC	1968 NYC	2001 NYC	1964 NYS	1967 MCC	1965 BOCA
Detection	No requirement	Smoke detectors to shut down HVAC fans to prevent smoke recirculation	Class E fire alarm system with voice commu-nication	Fire alarm system required; fire detection or sprinkler system is alternative	Not required	Fire alarm system required if not sprinklered
Suppression (Sprinklers)	No Requirement	Below grade only	Required if gross floor area >100,000 ft^2	Below grade only	Not required	Not required until 1984
Permitted Construction Class	1A	1A, 1B	1A, 1B, 1C with sprinklers	1A, 1B	1A	1A, 1B
Fire Separation (Compart-mentation)	3 h shaft enclosures; 1 h tenant separations (demising walls)	2 h shaft enclosures; 1 h tenant separations	2 h shaft enclosures; 1 h tenant separations; unsprinklered requires compart-mentation if >7,500 ft^2 or >15,000 ft^2 with smoke detectors	2 h shaft enclosures; 1 hr tenant separations	2 h hoistways; 1 h shaft enclosures; 2 h tenant separations every 10,000 ft^2	2 h shaft enclosures; 3/4 h tenant separations
Minimum fire resistance ratings:						
Ext. and int. bearing walls and columns supporting >1 floor	4 h	3 h	2 h	3 h	4 h	3 h
Floors including beams	3 h	2 h	1 ½ h	2 h	3 h	2 h

A.4.6 Means of Egress

The basic concept of occupant egress implemented in building codes involves the provision of a properly designed *means of egress* that is continuous and unobstructed from any point in the building to the outside. Proper design includes the width of the spaces and doors, direction of door swing, lighting and marking, protection from the fire and its effects, and geometry of stairs or ramps. Limits on travel distances to reach a means of egress and on common paths of travel, dead ends, and the provision of alternative means of egress if the primary path is blocked by fire are also basic concepts of egress design.

The means of egress described in building codes consists of three parts. The *exit access* is a corridor, aisle, balcony, gallery, room, porch, or portion of a roof over which an occupant must travel to reach the exit. The *exit* is a door leading to the outside or through a protected passageway to the outside, a smoke-proof tower, protected stairway, exit passageway, enclosed ramp, escalator, or moving walkway within a building. The *exit discharge* is the door to the outside, although some codes allow not more than half the exits to discharge onto a floor with an unobstructed path to the outside, and which is protected by sprinklers and a 2-h fire resistance separation from floors below.

Another concept found in the context of Means of Egress systems is that of *defense in place*. This is normally associated with occupancies where the occupants cannot escape such as hospitals or prisons, but may also be applied to refuge areas (sometimes called areas of rescue assistance) where people with disabilities await assistance or to areas in which occupants are being held temporarily while they await their turn to evacuate in a phased evacuation. Defense in place usually involves providing some protection against exposure to fire, heat, and smoke for the time needed to move these people to a safe place.

Egress System Design

The objective of the egress system design is to allow unimpeded evacuation of the building population without exposure to fire or smoke. Prescriptive building code regulations address this by specifying a population density (people per unit floor area) for each building use group, called the "occupant load factor." When multiplied by the floor area, the *occupant load* is obtained on which the egress system design is based (unless there is reason to believe that the actual load will be greater or the owner desires a greater allowance).

The means of egress is then designed to accommodate that occupant load on the basis of an egress width per occupant served, also specified in the building code. Values are specified for stairs and for other egress components, sprinklered and unsprinklered, and with special values for high hazard and institutional building occupancies to allow for higher egress speeds (high hazard) and greater number of wheelchairs or evacuation in patient beds (institutional), respectively.

The width of the egress system at each floor is sized to accommodate the number of occupants on that floor only. There is an additional requirement that the egress system width cannot become narrower in the direction of egress travel and beyond any convergence of two or more egress systems the capacity cannot be less than the sum of the capacities. These requirements are intended to account for the accumulation of flows from multiple floors.

For very tall buildings, it was recognized that the accumulating flow from a large number of floors would result in congestion in the stairways and a reduction of flow speeds. Widening stairways to increase the capacity has an economic consequence. Thus the concept of phased evacuation was developed where occupants are evacuated first from the three floors closest to the fire, while others wait their turn. Such systems require a voice communication system to manage the process by voice messages from a fire command center staffed by the fire service, and (e.g., in New York City) fire wardens on each floor directing the flow.

Prescriptive Egress Specifications

Traditional (prescriptive) building codes specify the design of egress systems by first, estimating the number of occupants in an area to be evacuated, second, determining the (combined) width of the exit system needed for that number of occupants, and third, dividing that width among the number of exits needed to achieve the travel distance limits. These codes further establish some minimum requirements for the number and width of exits and exit components. These minimum requirements seem to derive from a 1935 National Bureau of Standards (now NIST) publication titled “Design and Construction of Building Exits” (NBS 1935). A survey of buildings showed that the nominal 44-in. (2 units of width) exit stair was in common use, and a majority of buildings provided two such stairs. This report recommended that these be adopted as minimum requirements in building codes. This report also recommended the values for occupant load and capacity allowances discussed below.

For the most part, the egress design factors found in all of the model building codes are identical. In the IBC and NFPA 5000 model codes, design occupant densities (loads) range from 500 ft^2 (gross) per occupant (aircraft hangers, warehouses) to 5 ft^2 (net) per occupant (assembly, standing space). Common values are 100 ft^2 (gross) per occupant (business, industrial) or 200 ft^2 (gross) per occupant (residential). By multiplying occupant loads by estimated floor area, the number of people to be evacuated is obtained. These same values have appeared in the building codes for a long time.

The *means of egress* provisions in the (1968 through 2001) New York City Building Code use the “unit width” method of computing egress capacity. This method was previously found in all the model codes but was changed to the “inches per person” method in the late 1980s (e.g., the NFPA 101 Life Safety Code changed to the “inches per person” method in its 1988 edition). The major reason for the change was that the capacity of elements of the egress system was measured in 22 in. increments (called a unit of exit width) with remaining fractions only credited in half units (12 in. or more). Thus the “inches per person” method allows egress credit for exit elements that may have non-standard dimensions. The New York City Building Code (1968 through 2001) requires at least two exits per floor for business occupancy (Group E) in buildings taller than 60 ft and it permits 80 people per (22 in.) unit of exit width and 60 people per unit width on stairs. These are identical to the values found in the contemporaneous codes (1965 BOCA and 1968 NFPA 101) reviewed. For example, for a floor space of 30,000 ft^2, 5 unit widths of stairs would be needed. Thus three 44 in. wide stairs (the minimum permitted width) would meet the New York City Building Code requirement. New York City further permits scissor stairs (an arrangement where two stairs are intertwined in a single shaft) with openings located at least 15 ft apart (C26.602.3), which are prohibited in most other building codes.

Both the IBC 2000 and NFPA 5000 model codes, as well as most building codes based on them (but not 2001 NYC), now determine the capacity of the egress system by specifying the width per person for egress system components. With the exception of hazardous and health care occupancies, both the IBC (without sprinkler protection) and the NFPA 5000 Code (sprinklered or not) specify the same egress system width of 0.3 in. per occupant in stairways and 0.2 in. per occupant elsewhere. The IBC reduces egress capacity where sprinklered to 0.2 in. per occupant in stairs and 0.15 in. elsewhere. The egress capacity of the exit system is the smallest capacity of any component. For example, a 34 in. (clear width) door leading into a 44 in. (clear width) stair have capacities of 170 and 147 occupants, respectively. Thus the exit capacity is the smaller of the two, or 147 occupants. The minimum number of exits specified in both model codes is two for populations up to 500, three from 501 to 1,000, and four if over 1,000.

Finally, building codes specify maximum travel distances to an exit by occupancy and presence of sprinklers, and the same values are found in all the codes, including New York City. For example, in the 1968 New York City Building Code, the maximum travel to an exit for business occupancy is 200 ft for unsprinklered construction and 300 ft for sprinklered construction. The IBC 2000 code specifies 200 ft (unsprinklered) and 250 ft (sprinklered) for most occupancies, except for business which is allowed 300 ft if sprinklered. The NFPA 5000 code specifies travel distances without sprinklers of 100 ft (for hotels, apartments, and mercantile), 50 ft (for health care and educational), or 200 ft (for business, industrial, and assembly). When fully sprinklered, these increase to 200 ft (for hotel, apartments, educational), 250 ft (for mercantile, industrial, assembly) and 300 ft (business). While most buildings will require two or more exits, the travel distance requirement only applies to the distance from any point to the closest (single) exit. The distance to any other exit(s) is unregulated.

Elevators

Currently there are no U.S. building codes that permit elevators to be used as a means of occupant egress in emergencies, and ASME A17.1 (ASME 2000) requires signs at all elevators warning that they shall not be used in fires. There are some recent exceptions to this, but these are limited to special cases. For example, NFPA 5000 permits protected elevators as a secondary means of egress for air traffic control towers and the City of Las Vegas accepted elevators as a primary means of occupant egress from Stratosphere Tower based on a performance-based design (Bukowski 2003).

U.S. building codes (including New York City) require *accessible elevators* as part of a means of egress that may be used by the fire service to evacuate people with disabilities. These elevators must comply with the emergency operation requirements of ASME A17.1 (Phase II emergency operation by the fire service), be provided with emergency power, be accessible from an area of refuge or a horizontal exit (unless the building is fully sprinklered), and operate in a smoke protected hoistway. Phase II operation involves the use of an elevator by a firefighter for fire service access or for rescue of people with disabilities performed under manual control (with the use of a special key).

A.5 PRELIMINARY FINDINGS

The 1968 New York City Building Code was compared with contemporaneous building codes to determine whether there were significant differences in code provisions. In addition, the 2001 New York City Building Code was also compared to examine the changes resulting from the adoption of Local Laws and rules. The comparison was limited to provisions related to structural stability, fire safety, and egress. In general, it was found that the majority of the provisions were similar among the four codes that were compared. It was also found that the New York City Building Code was more advanced in certain areas than the other three contemporaneous codes (1964 New York State Building Construction Code, 1967 Municipal Code of Chicago, and 1965 BOCA Basic Building Code). The following summarizes the major findings of the code comparison.

A.5.1 Provisions Related to Structural Stability

Dead Load

The New York City Building Codes (both 1968 and 2001 editions) allow lower than 20 psf for uniformly distributed partition loads for partitions that weigh less than 200 plf, while the other codes compared prescribed a minimum uniform partition load of 20 psf. As a reference, a 10 ft high partition made of 1/2 in. thick gypsum wallboard on both sides of 2 by 4 wood studs spaced at 16 in. on center weighs about 60 plf. Except for the partition load provision, other dead load provisions in the five codes compared are similar.

Live Load

The five codes compared had similar minimum live load provisions. They all permit live load reduction for the design of columns and floor framing members. The amount of reduction allowed varies among the codes. While the 1967 Chicago Municipal Code allowed only a maximum of 15 percent reduction for floor-framing members (beams and girders), other codes allowed as much as 60 percent reduction (see Table A–3). The amount of reduction allowed for columns is about the same for all five codes (see Fig. A–1).

Wind Load

The general trends of the specified wind pressure distributions along the height of a building in the five codes compared are similar. However, specific design wind pressure values vary as much as 10 psf at specific heights. For tall buildings, like the WTC towers, the 1965 BOCA Basic Building Code would produce the largest shear force and bending moment at the base of the building.

The 1968 New York City Building Code allows determination of design wind pressure based on wind tunnel tests with approval by the Building Commissioner.

Earthquake Load

In the 1960s, only the BOCA Basic Building Code had the earthquake design provisions, which were based on the Uniform Building Code. The 2001 New York City Building Code contains the earthquake design provisions that are based on the 1997 Uniform Building Code.

Others Loads

The 1968 New York City Building Code is the only code among the contemporaneous codes compared that has provisions to consider loads due to thermal expansion/contraction of structural members and shrinkage of reinforced concrete members. The New York City Building Code also included language on the distribution of loads among structural members in a building.

Referenced Design Standards

The 1968 New York City Building Code and the other contemporaneous codes compared, except the 1964 New York State Building Construction Code, make reference to the same national design standards for steel and reinforced concrete.

Building Alterations

All codes compared, with the exception of the 1964 New York State Building Construction Code, had similar provisions on whether alterations were required to comply with the current building code. In general, alterations need to comply with the current code when the alteration is a significant portion of the building size or value (see Table A–5). The New York State code, on the other hand, required any alteration to comply with the code.

Construction Inspection

The codes that were compared include provisions related to inspection of materials and methods during construction. The specific requirements, however, are not similar. The 1968 New York City Building Code distinguishes between "controlled inspection" that require supervision by a design professional and those not so designated as controlled, which can be tested by the person superintending the use of the material. The New York City Building Code required controlled inspection of sprayed-on fire protection, but it did not specify required tests.

Bracing

Only the New York City Building Code among the codes compared included provisions on bracing of compression members. The New York code requires that members designed to brace compression members (for example, columns), be proportioned to resist 2 percent of the design compression load in the member being braced.

A.5.2 Provisions Related to Fire Safety

Construction Types

The building codes compared classify building constructions into different types depending on the combustibility of the construction materials. The New York City Code uses two types, noncombustible and combustible, whereas modern model codes have adopted five types: fire resistive (Type 1); non-combustible (Type 2); combustible (Type 3); heavy timber (Type 4); and ordinary (Type 5). These types are typically sub-divided into classes such as Type 1A and Type 1B.

The cornerstone of fire safety of construction is the "height and area" table that defines the limiting floor and area and building height for different construction classifications (1A, 1B, and so forth) and occupancy groups. In the case where a building could be assigned to more than one construction classification, the codes are silent on which classification should be used, and the selection of the building classification is at the discretion of the owner/architect.

Compartmentation

In 1973, Local Law 5 was adopted by New York City, which required that large, open floors in existing office building over 100 ft in height be subdivided by 1-hour separations into areas not greater than 7,500 ft^2. Areas could be increased to 15,000 ft^2 with 2-hour separations and smoke detectors. Unlimited floor areas were permitted where fully sprinklered.

Sprinklers

In 1985, Local Law 16 was adopted in New York City, which limited Type 1B construction to buildings of 75 ft or less unless they were fully sprinklered, for which there were no height or floor area limitations.

A.5.3 Provisions Related to Egress

The 1968 New York City Building Code contained similar requirements to the other contemporaneous codes, which were compared, for the number and capacity of exits and stairs and for the design occupant load. The New York City Code permitted scissor stairs (two stairs in one shaft separated by a fire-rated partition) with doors located at least 15 ft apart, whereas other building codes prohibited scissor stairs.

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